A Roof Vent System Which Prevents Roof Loss / Lift Off in High Winds

ARGUMENTS / PROSECUTION

Addressing the issue of patentability, I would like to outline what I understand the criteria for the grant of a patent to be. I will then explain how I see my invention fulfilling those criteria. Finally, I will compare my invention to the prior art that I have found in order to highlight the differences.

To be patentable in the U.S. an invention must be new, useful, and unobvious from the prior art. A utility patent must fit into one of four categories:

1) A process
2) A machine
3) An article of manufacture
4) Composition of matter

A process can also include a new method of making or using something already known in the other categories. My invention I believe can be looked at as a new method of using something already known in another category. Previously, vents have been used for the purpose of equalizing pressure. Several patents have been written and granted for a variety of vent designs that act to equalize or relieve pressure differences across a roof. No one however, has made use of a vent's ability to limit the maximum pressure difference that can occur.

I am applying for the grant of patent rights for a roof vent system. The new and useful thing which this system achieves, is the prevention of a pressure difference greater than a specified value across the roof, (i.e. between the interior and exterior of the building) and thus the prevention of roof loss. (The specified value is set so as to be lower than the pressure difference needed to lift off the roof). It is important to note that it is only as a vent system, (an entity in itself) installed using specific parameters that the objective of the invention can be achieved.

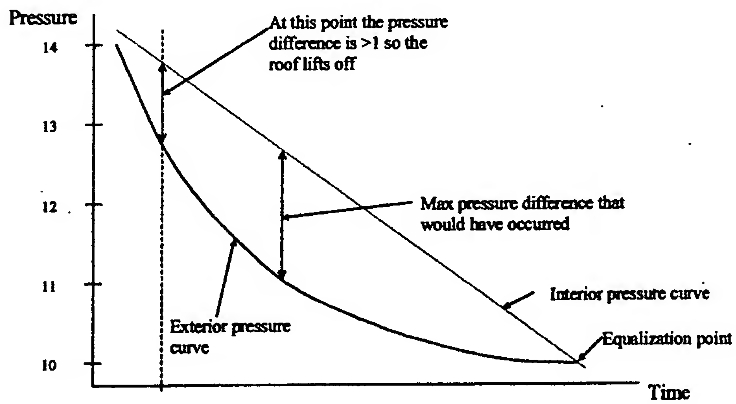
Background of Invention

The use of venting in the roof of a building to equalize pressure is not new. There are several patents that I have found in my search which deal with this. In all cases they have as their stated objective the equalization or relief of a pressure difference between the interior and exterior of the roof. ~~I stress again that~~ This is distinctly different from what my roof vent system achieves. Any hole such as a chimney flue or even a crack in a roof will allow for the equalization of pressure eventually. It will not necessarily however, prevent a pressure difference that is sufficient to lift off the roof, from developing. (This pressure difference is quantified by measuring the weight/area of the roof, the tensile strength of the roof material, and the tensile strength of the connections attaching the roof to the walls.)

<u>Graphical representation of the distinction between using a vent to equalize pressure and my vent system which prevents a specific pressure difference from occurring (arbitrary values and units used)</u>

<u>Use of vents to equalize pressure</u>

in drawing

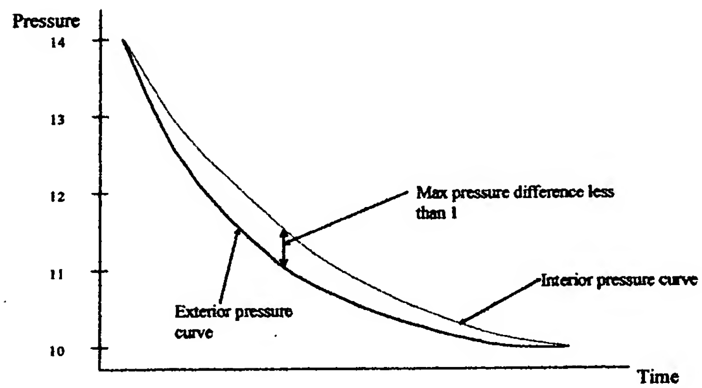


Any pressure difference greater than 1 unit has been shown sufficient to lift off the roof. It can be seen that as soon as the pressure difference became greater than 1 the roof blew off. Equalization of pressure through venting would hypothetically have been reached if

the roof had remained on. As it happens equalization occurred much sooner (as soon as the roof came off).

<u>Use of vents to limit the pressure difference across a roof</u>

in drawing



Again, let it be accepted that roof lift off (loss) occurs at 1 unit pressure difference. At no time is a pressure difference allowed to occur across the roof which is greater than 1. Thus the roof will not lift off.

To ensure this relationship between the two curves, a calculation that takes data about the worst-case scenario pressure change above a roof, the volume of the building in question and various other parameters is used. The resulting equations generate a value for the surface area of open roof venting required to ensure that the interior and exterior pressure curves maintain acceptable relative positions. No equations of this nature are evident in the prior art that I have uncovered. This fact highlights the claim that my invention is new and distinct from the prior art, because it is only through the use of such equations that the ability of a vent to limit a pressure difference actually becomes useful. Thus, prior art showed an appreciation of a vents ability to equalize pressure, however no understanding of the fact that a vent may be used to limit a pressure difference is in evidence.

In summary, my arguments are that:

1. A roof vent system that prevents roof loss due to high winds is certainly useful.
2. It is new as far as any prior art that I have uncovered. The use of vents to equalize or relieve, pressure is not new, but the use of a roof vent system to prevent a pressure difference greater than a specified value across a roof is new.
3. I feel that once this has been explained to someone it should be obvious. However, I think that everything is 'obvious' once one has had it explained and understands it. The best argument for not being obvious is probably that if this invention is very useful, and it has not been patented or implemented anywhere, then it cannot be all too obvious.

DETAILED DESCRIPTION

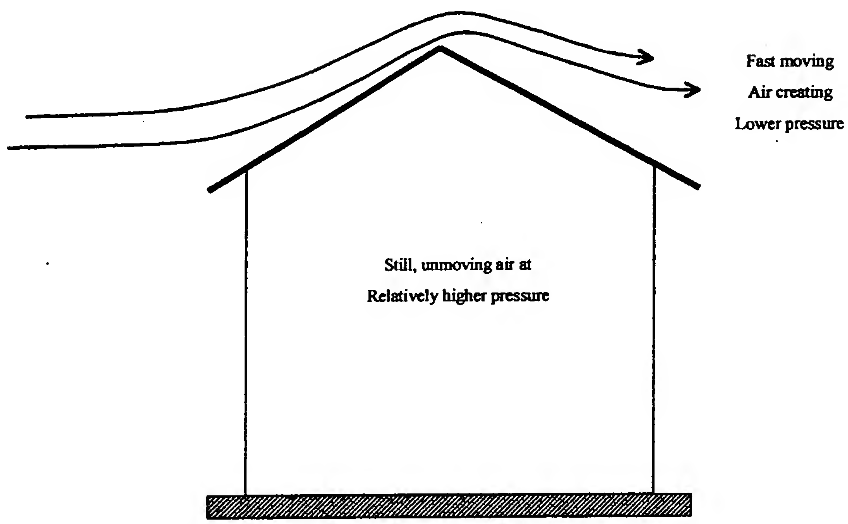
SUMMARY

This system works by limiting the pressure difference that may occur across a roof. Initially a quantification of the greatest pressure drop that can possibly occur above a roof per unit time must be arrived at. (Data collected from hurricane and tornado events). Next, the allowable pressure difference that may occur across the roof must be measured (the allowable pressure difference is less than the pressure difference required to lift off the roof). This allowable pressure difference acts as the maximum potential driving force for air evacuation from the interior of the building. It also dictates the parameters within which the building's internal pressure curve must follow the external curve. Finally the volume of the building must be measured. From this the mass and volume of air that must be evacuated to keep the internal pressure curve within the acceptable pressure difference from the external curve can be calculated. Three equations for which there are three unknowns can then be written. Thus a solution for the minimum vent area required can be arrived at.

In the simplest sense, a known force is expelling a known quantity of air from an enclosed space. It must be done within a set time limit. Thus the value of the minimum area of venting required to do this can be solved for.

FORCES ACTING ON A ROOF

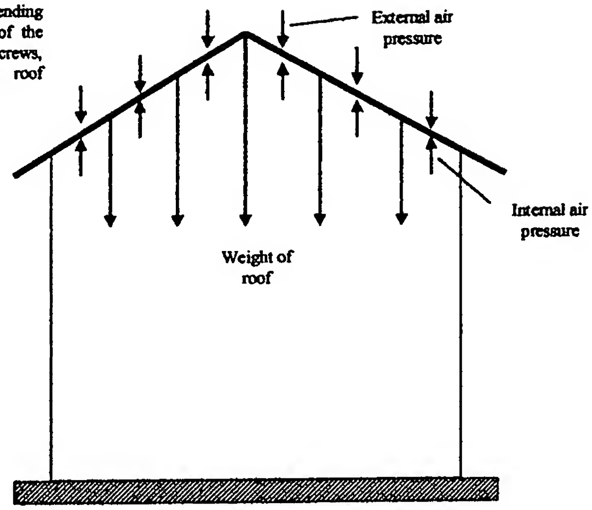
As fast flowing air passes over a roof, there is a resulting lowering of pressure. (Venturi effect and turbulence)



Thus the pressure outside the roof is lower than the pressure inside the roof. Pressure is a force/unit area. In order for the roof to lift off of a house, the forces acting upwards must be greater than the forces acting downwards.

Forces Diagram

The weight of the walls and concrete pad can add to the effective roof weight depending upon the tensile strength of the connections (e.g. nails, screws, brackets, hurricane clips, roof beams)



In the simplest equation format, if

$$\left[\frac{\text{Weight of Roof}}{\text{Unit Area}} + \text{External Pressure} \geq \text{Internal Pressure}\right]$$

then a roof will always stay on. There is no net force upwards.

It should be possible to quantify with a degree of accuracy the minimum tensile strength of the connections linking the roof to the walls as well as the minimum tensile strength of the roof material itself. These factors can then be incorporated into the above equation to give a more accurate value for the maximum allowable pressure difference.

$$\frac{\text{Weight of Roof}}{\text{Unit Area}} + \text{Tensile strength of connections} + \frac{\text{External Pressure}}{\text{Unit Area}} \geq \frac{\text{Internal Pressure}}{\text{Unit Area}}$$

$$\frac{\text{Weight of Roof}}{\text{Unit Area}} + \text{Tensile strength of connections} \geq \frac{\text{Internal Pressure - External Pressure}}{\text{Unit Area}}$$

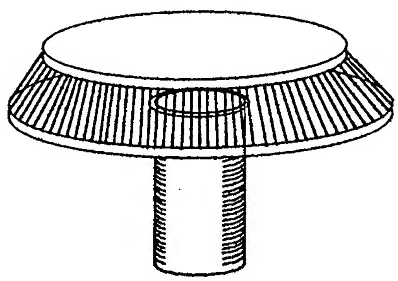
These equations illustrate that the air pressure difference between the interior and exterior of the building acting upwards must at all times be less than the weight/area of roof plus the factored effect of the tensile strength of connections and roofing material acting downwards.

In order to allow air to flow across the roof and thus control this pressure difference vents are used.

PREFERRED VENT DESIGNS

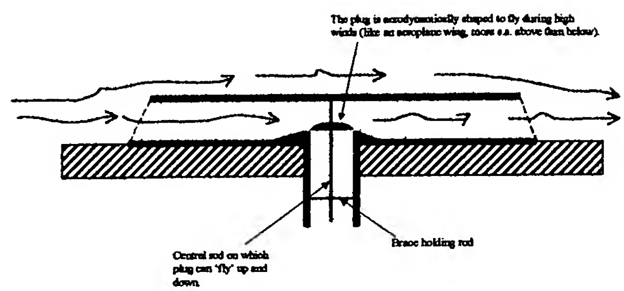
Ideally one wants the vent design to be as streamlined as possible so that the air passing through the vent is travelling at the same speed and creating the same lift effect as the air flowing over the adjacent roof. Wind tunnel tests that quantify the friction of air flowing through the vents will allow a compensating adjustment of the calculated minimum venting area required. (This friction is that experienced by the air passing in under the vent cap and out the other side, not the air moving from the interior of the building through the vent to the exterior.)

1) Vent design (A)

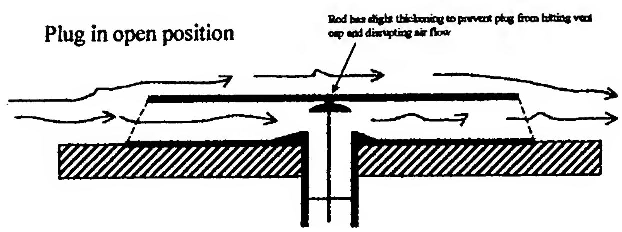


Cross-sectional view

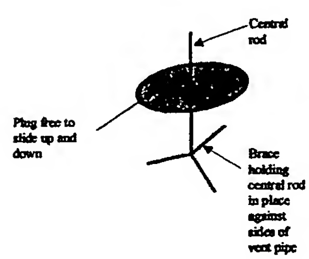
Plug in closed position



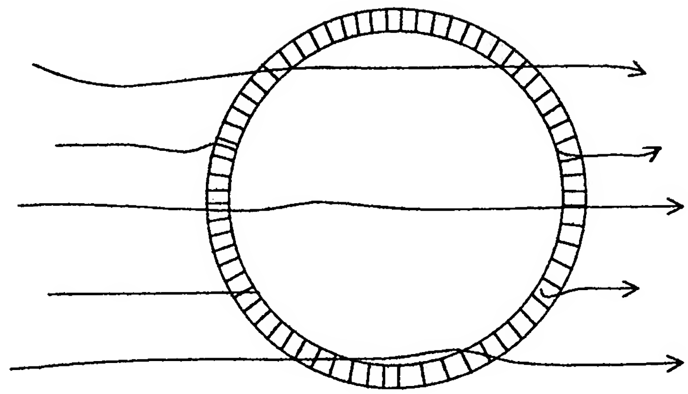
Plug in open position



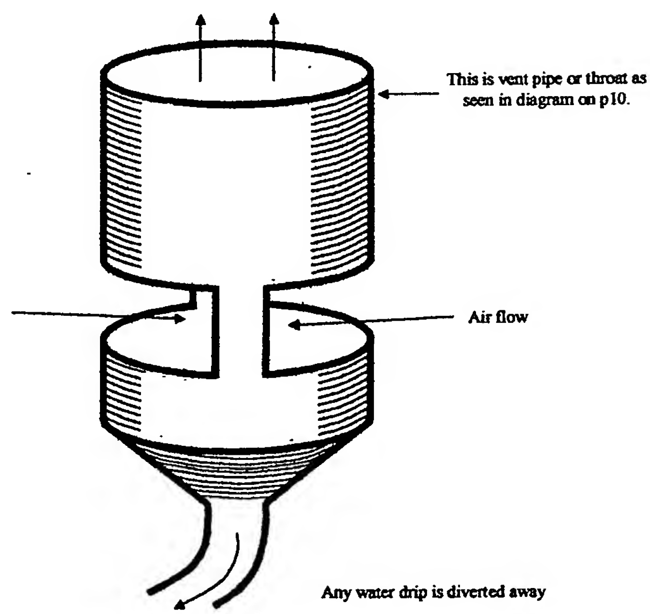
Details of plug shaft and brace mechanism



View from above

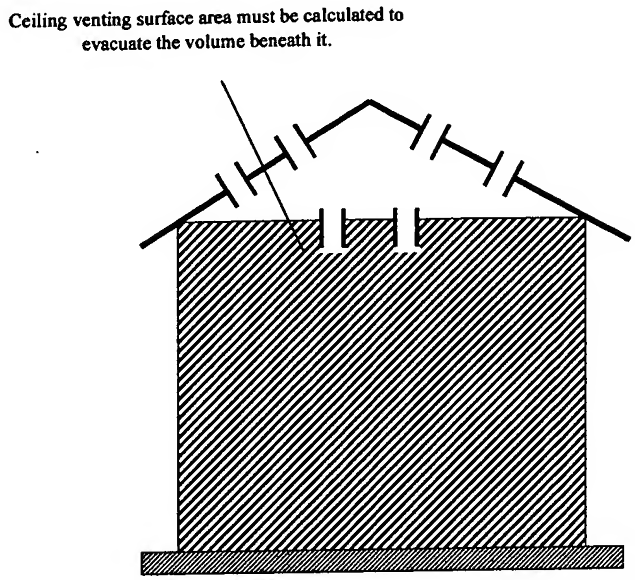


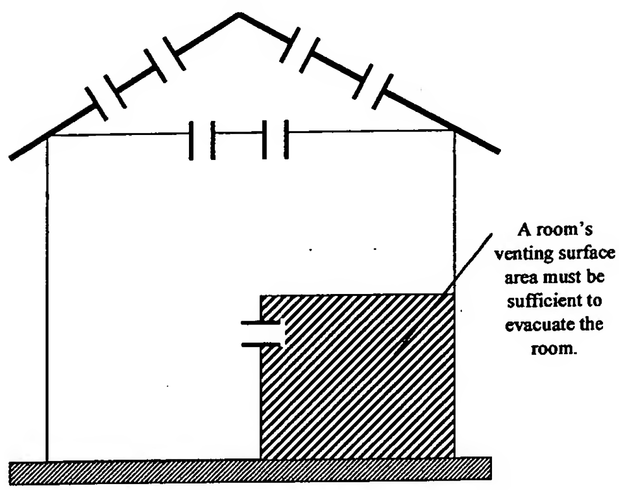
Optional Water Removal Mechanism



Vent (A) Performance Points

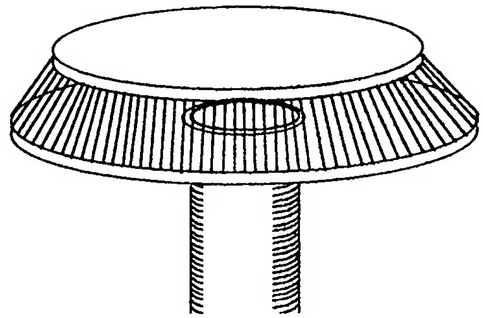
1) Cap prevents rain from entering, (even most horizontally blown rain).
2) Cap is smaller than base plate so that bars slope in. This makes it more difficult for blown debris to catch on the vent.
3) Vertical bars are spaced such that the gap size doesn't allow bees access. (vents cannot become hive sites)
4) Any water that does enter the vent shaft is collected and channeled through a tube into the drains. The tube might alternatively direct the water outside the building, if this proves easier.
5) The central plug is 'free floating' on a central shaft. Its weight / area is, let us say 60% of the maximum allowable pressure difference. This means that at a pressure difference greater than 60% of the maximum allowable the plug will be pushed up, thus opening the vent. (The 60% figure is set so that the vent will be open by the time the maximum allowable pressure difference is reached. I.e. wind acceleration from 60% to 100% does not outpace the speed at which the vent opens. This 60% value might need to be 50% or 90%, whichever is calculated as appropriate.)
6) Once the central plug is pushed up it acts like an airplane wing. Air rushing through the vent 'flies' the central plug up on its shaft. The vent stays open as long as high-speed winds are blowing through it. When the wind speed drops the plug sinks down to close the vent.



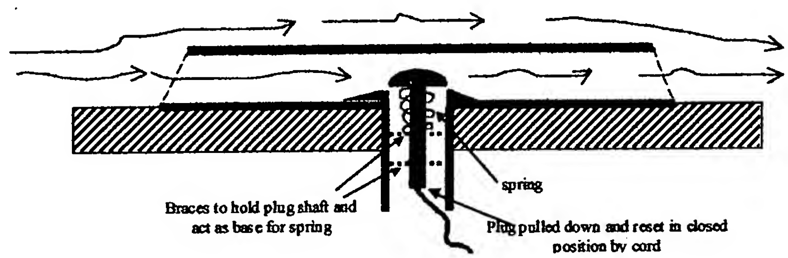


The flow route may be designed as one wishes, but everything must flow out through the roof in this open, free-flowing vent system.

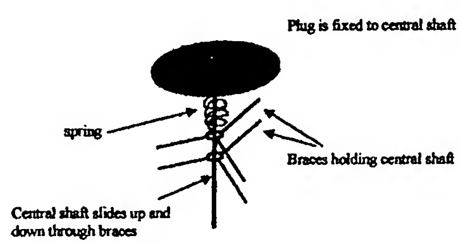
2) Vent Design (B)



Cross-sectional view



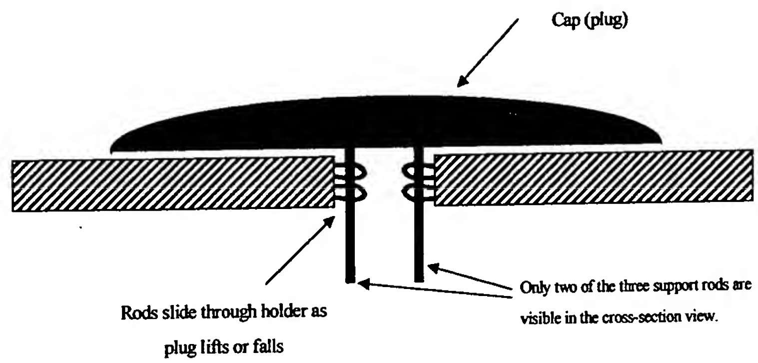
Details of plug/braces and shaft mechanism



3) Vent design (C)

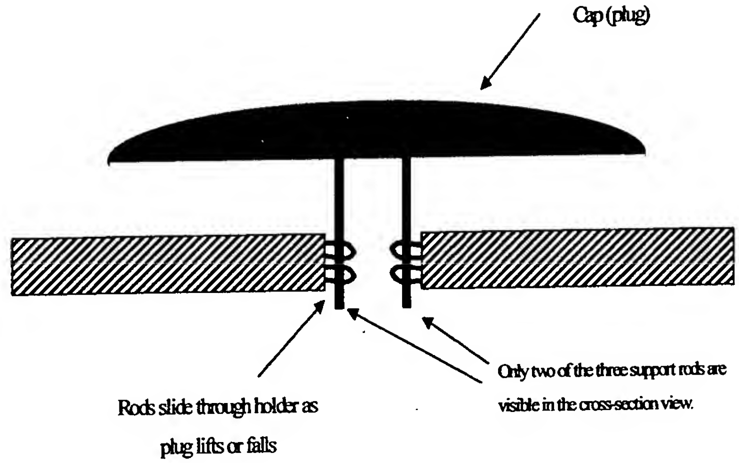
Cross-sectional View

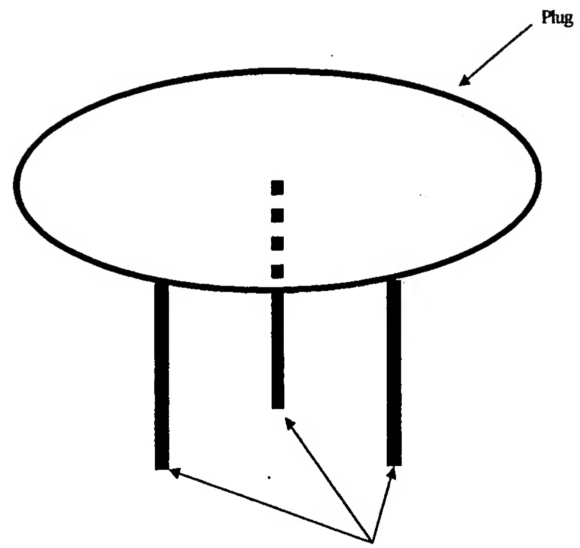
Closed Position



Cross-sectional View

Plug in open position





Plug is fixed to support rods. The rods slide up and down through holders to allow plug to lift or drop,

Vent (C) Performance Points

1) Cap prevents rain from entering, (even most horizontally blown rain).
2) Any water that does enter the vent shaft is collected and channeled through a tube into the drains. The tube might alternatively direct the water outside the building, if this proves easier.
3) The central plug and its three support posts are free floating. Its weight / area is, let us say 60% of the maximum allowable pressure difference. This means that at a pressure difference greater than 60% of the maximum allowable the plug will be pushed up, thus opening the vent. (The 60% figure is set so that the vent will be

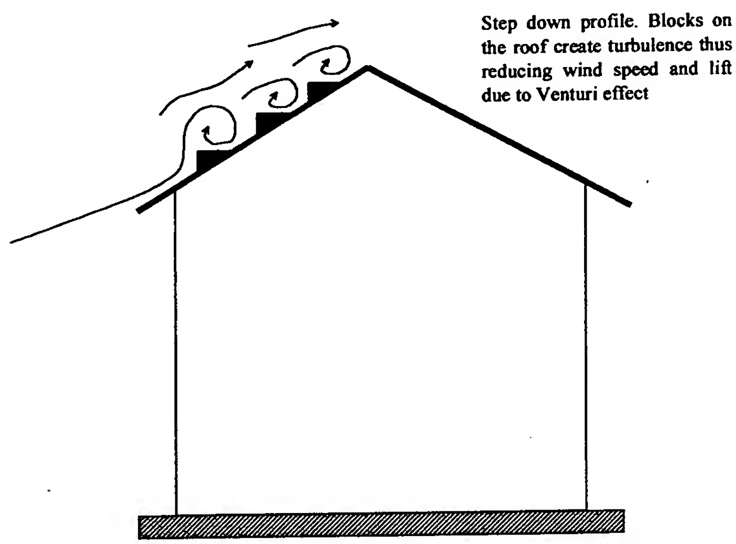
open by the time the maximum allowable pressure difference is reached. I.e. wind acceleration from 60% to 100% does not outpace the speed at which the vent opens. This 60% value might need to be 50% or 90%, whichever is calculated as appropriate.)

4) Once the central plug is pushed up it acts like an airplane wing. Air rushing through the vent 'flies' the central plug up on its shaft. The vent stays open as long as high-speed winds are blowing through it. When the wind speed drops the plug sinks down to close the vent.

All of the preferred vent designs need only be opened in hurricane/tornado conditions. The rest of the time they remain shut to prevent heat loss from the house.

CONSIDERATIONS OTHER THAN VENTS

1) Increasing the weight of the roof will make it more difficult to lift off (e.g. attach weights to rafters, or the plywood roof sheeting). The disadvantage to this however, is that in the event of a building collapsing or being blown down there is the potential for a lot of heavy weight landing on someone.
2) Decreasing wind speed over the roof. (I am not convinced that it would be possible to effectively limit wind speed by creating a certain roof profile)



3) Increasing the tensile strength of roof connections and roofing materials. This should be effective, however it means replacing existing roofs with higher quality materials, which is expensive (both the materials and the cost for replacement).

Each methodology has its distinct advantages and drawbacks. I suspect though, that the cheapest and most effective way to prevent a building from loosing its roof will prove to be the vent system approach.

THE USE OF VENTS, A CALCULATED NUMBER (SURFACE AREA OF OPEN VENTING) WITH RESPECT TO VOLUME OF BUILDING.

In order to calculate the surface area of open venting (number of vents) that a given building requires to prevent roof loss the following series of steps must be taken.

A) The greatest pressure drop per unit time that can occur above a roof must be quantified.

B) The pressure difference across the roof that is allowable for each type of roof construction must be measured. (i.e. the pressure difference that a given type of roof will tolerate before it is blown off)

C) Using the information from A and B the pressure change (drop) per unit time that must occur inside the building can be quantified and the venting area required to achieve this can be calculated.

A)

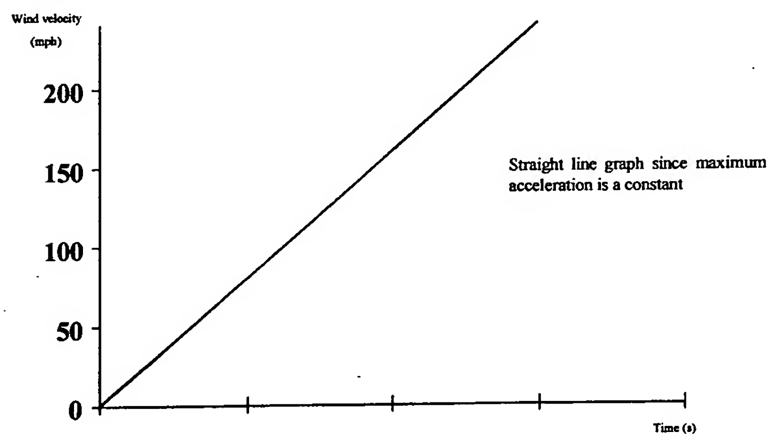
1) Data of wind accelerations must be taken. (Can be found or measured at a meteorological station, military records, or from storm chasers recordings) What is needed is the maximum wind acceleration ever recorded, i.e., the fastest change of wind speed observed for the type of storm event that you wish to rate the building for.

2) The longest time for which wind has accelerated must also be measured. (I.e. Wind accelerating at a maximum value for a maximum time period will give a maximum pressure change per unit time that may occur above a roof.)

3) Alternatively as an almost overkill approach take the fastest wind velocity recorded (e.g., might be 180 mph in hurricane situations or up to 300 mph in a tornado). The data you choose to input is aimed at quantifying the theoretical worst-case scenario for pressure change above a roof.

Take the value of the maximum recorded acceleration of wind and apply it from velocity = 0 up to a maximum wind speed expectation. This will give the greatest pressure change over the smallest time period that can theoretically occur above a roof. (One might even choose as insurance to put in values slightly larger than have been measured.)

Graph of Maximum Measured Acceleration of Wind from 0mph to Maximum Wind Speed Expected
(Hurricane protection speed)
(an example, not real data)

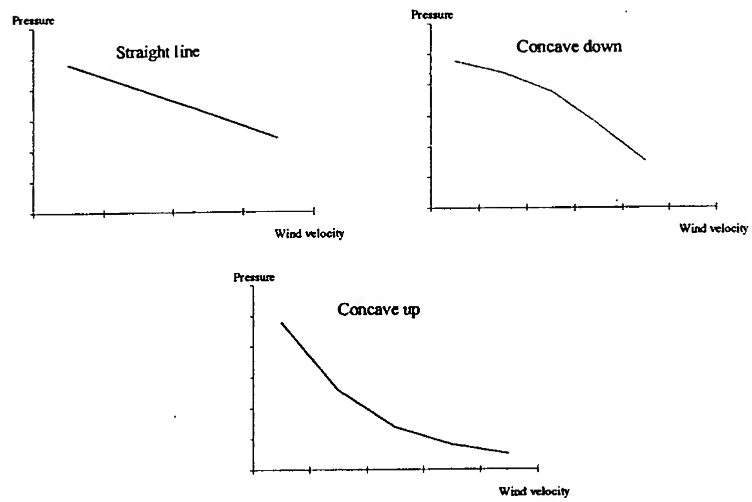


The next step is to link a given wind speed to a specific pressure value. This data can be generated using a wind tunnel and any suitable pressure-measuring device.

Using the wind tunnel blow wind speeds from 0 mph up to your maximum expected velocity. Take the pressure-measuring device and measure the greatest pressure drop that corresponds to each wind speed. From this a graph of pressure versus wind velocity can be plotted. Obviously initial atmospheric pressure may vary, however it is the pressure

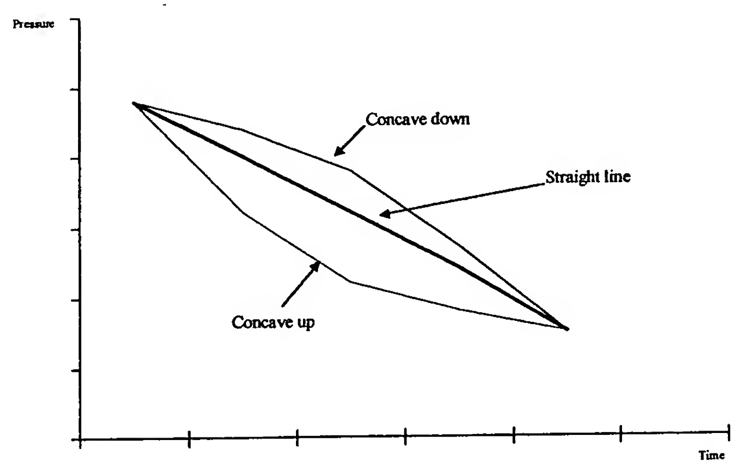
change between velocity 0 and the maximum expected velocity that it is important to quantify.

Potential Graphs of pressure w.r.t. Velocity of Wind
(actual graphs will take the form of one or some combination of the following)



Using the pressure relative to velocity results plot pressure versus time based on the maximum measured wind acceleration to reach the maximum expected wind speed. This produces a graph, which describes the greatest pressure change that can occur in the shortest possible time above a roof: In other words, the worst-case scenario that would need to be dealt with.

Graph of Pressure w.r.t. Time
(graph will be in one or some combination of these forms)



Incorporated with this must be a consideration of the atmospheric pressure shift that is associated with ambient 'still air' atmospheric pressure (recorded as barometric pressure). The rapidity with which this may cause a pressure change above a given location should be factored in with the maximum pressure change value associated with high-acceleration winds.

An alternative and supporting quantification method would be to set a continuously recording pressure-sensing device out in various high wind events (hurricane, tornado). This would provide data for comparison with wind tunnel tests.

It is perhaps important to note that rating a building for a certain wind velocity is misleading as a rating standard. This rating is done in a wind tunnel where air speed is gradually increased to a certain value. This means that the pressure drop associated with high-speed wind above the roof is also gradual. Any minute gaps in a model building's joints, which are inevitable in any construction, will allow the relatively higher-pressure air inside the model to be drawn out. Thus as long as the air velocity increase above the roof is gradual, the roof may not lift off. True control however, is only achieved when worst-

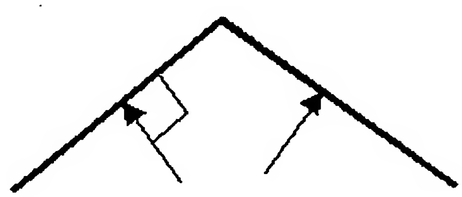
case pressure drops per unit time are quantified (i.e. maximum wind accelerations and their maximum duration). If wind velocity is the only yardstick used one might find that a roof will withstand gradual wind speed increase up to 110mph, but a sharp gust between 60mph and 90mph is sufficient to lift off the same roof.

B)

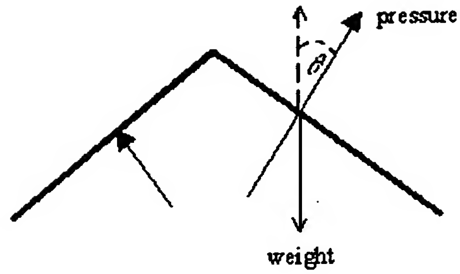
The pressure difference between the inside and outside of the building must at all times be below a certain value. That value is the one at which point the roof will lift off. As explained earlier this value can be calculated very exactly using the weight of the roof/unit area, the tensile strength of attachments to walls, wall weight etc. However, one could also just build in a safety margin and make the maximum allowable pressure difference the weight/area of the roof ($^4/_5$ weight/area or $^3/_4$ i.e., whatever safety margin one chooses to create).

I will show scenarios using the weight/area of the roof as the allowable pressure difference.

It should be noted that pressure acts perpendicularly to a given surface.



So in the case of a roof the pressure acts perpendicularly to the roof surface whereas weight acts directly downwards.



Thus more accurately the pressure difference must be less than the weight/area ($\cos\vartheta$) to prevent roof loss.

Pressure inside - Pressure outside = P^* (pressure difference)

P^* must be less than roof weight/area ($\cos\vartheta$).

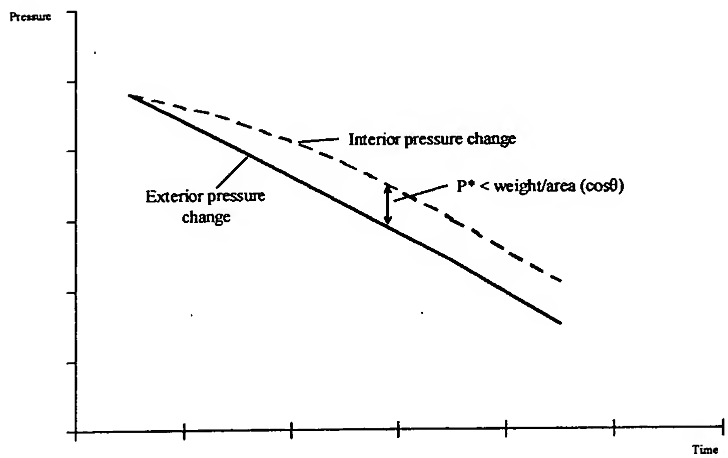
$P^* <$ weight/area ($\cos\vartheta$).

<u>C)</u>

Knowing the worst case exterior pressure change (worst-case scenario data) one knows what the interior pressure must match to stay within the allowable P^*.

Demonstration Graph (straight line example) of Exterior and Interior Pressure Changes

(exterior pressure is from worst case scenario data)



The above graphically defines what the interior pressure curve must be to be useful (i.e., prevent roof loss). Now it is necessary to calculate the area of roof venting (number of vents) necessary to achieve this.

1) Calculate the number of moles of gas (air) which must be removed from the interior of the building to bring the pressure difference within the allowable P^* at the point of lowest external pressure (max wind velocity). The interior of a building can be treated as a closed system, and the ideal gas equations can be applied.

Using the gas equation PV = nRT

P = pressure	n = number of moles	
V = volume	R = gas constant	T = temperature

I will be using the sign ↓ to indicate a known value

The initial interior pressure = initial exterior pressure.

The external maximum pressure change quantified in section A) does not have set starting and finishing points. The value represents only a maximum pressure change, which can be encountered. In a building with fixed volume and where R and T are constants it does not matter what starting point is taken. Whatever your starting pressure, if the maximum potential pressure change is subtracted from this the number of moles to be evacuated is always the same. (Within the constraints of the ideal gas equations). Later, however, when a value for the average pressure is required in order to calculate the volume of air being evacuated through the vents, a set starting point is needed. This set starting point should be the lowest barometric pressure recorded in association with the high wind event for which you are rating the building. This will maximize the volume of air to be evacuated thus providing a built in safety margin.

Thus the number of moles of gas initially inside the building can be calculated:

$$\overset{\downarrow}{P}\overset{\downarrow}{V} = n\overset{\downarrow}{R}\overset{\downarrow}{T}$$

$$\left[n = \frac{PV}{RT}\right]^{*} \text{ call this } n_i \text{ (n initial)}$$

Pressure is known/set as explained above
Volume of building is known/measured
R is the gas constant
T must be set
Temperature can be set at a typical value for the high wind event that you wish to rate the building for. (To be on the safe side, set the temperature at a lower value than it is ever likely to be: This will make the n (number of moles) to be evacuated larger than it will ever have to be. I.e. another built-in safety margin).

For the final interior pressure, take the value of final exterior pressure + P^*, since it need only be low enough to remain within the allowable P^* constraint.

Again using

$$\overset{\downarrow}{P}\overset{\downarrow}{V} = n\overset{\downarrow}{R}\overset{\downarrow}{T}$$

$\left[n = \dfrac{PV}{RT}\right]$ * call this n_f (n final)

Again, n (number of moles) is calculated and this n_f represents the maximum number of moles that may remain in the building to meet the P^* constraints which have been set.

Thus n_i - n_f = n moles of gas which must be evacuated from the building to keep P^* within its set constraints.

This n moles of gas will have a certain mass (i.e., composition of air %N, 0_2, $C0_2$, etc.) which can be calculated.

The volume of gas that must leave the building can also be calculated if the number of moles that must be evacuated is known.

Using $\overset{\downarrow}{P}V = \overset{\downarrow}{n}\overset{\downarrow}{R}\overset{\downarrow}{T}$ $\qquad$ $\left[V = \dfrac{\overset{\downarrow}{n}\overset{\downarrow}{R}\overset{\downarrow}{T}}{\underset{\uparrow}{P}}\right]$

n is known

R is constant

T has been measured/set

P average pressure can be calculated

Pressure is changing over the time period. A fixed number of moles of gas will occupy more volume at low pressure and less at high pressure. By using the value of the average pressure over the time period, the volume of air that must exit can be calculated.

Summary of what is known for any given building

(I.e. what can be calculated)

1) The time over which the pressure change occurs (worst-case scenario data).
2) The number of moles that must be evacuated from the building.
3) The mass of gas that must be evacuated.
4) The volume of gas that must be evacuated.
5) The P^* (this is measured for a given roof material and is a set value).

Now it is possible to write some equations.

(1) The equation for the volume of air exiting the building

volume *(vol)* = vent area *(area)* × *(v)* average air velocity through vents × *(t)* time air is flowing through vents

(2) Pressure = $\frac{\text{Force}}{\text{area}}$

This is the driving force of the air leaving the vents (P^*).

$$P^* = \frac{\text{Mass of air } (m) \times \text{acceleration } (a)}{\text{area}}$$

(3) We have set a maximum allowable P^*. This means that acceleration is constant once P^* is reached. (P^* is constant and thus acceleration is constant over the critical time period.) The following equation can be written when acceleration is constant and it acts to link the first and second equations.

$$(v) \text{ velocity (average)} = \frac{a \text{ (acceleration) } t \text{ (time)}}{2}$$

This equation is only true if the initial velocity is zero. That is not the case here. When P^* is reached the initial air velocity through the vents is definitely not zero. This means that the actual average velocity generated by this P^* will be higher than the value given by this equation. It therefore follows that the minimum vent area

given by this equation will be slightly larger than the actual minimum vent area required. This can be looked at as a cushion, or safety measure. A more complex and accurate equation can I am sure be generated later if necessary. I will use this simple equation to illustrate that it is possible to quantify a minimum vent area required to keep a P^* value within its set constraint.

So taking these three equations with the three unknowns, it is possible to substitute and solve for a minimum vent area required to ensure that P^* stays within its limit.

(1) $$vol = area \times v \times t$$

(2) $$P^* = \frac{force}{area} = \frac{ma}{area}$$

(3) $$v = \frac{at}{2}$$

Substituting (3) into (1) gives (4)

(4) $$vol = area \times \frac{at}{2} \times t$$

from (2) $a = \dfrac{area\,P^*}{m}$ substitute this into (4) to give (5)

(5) $$vol = area \times \frac{area\,P^*}{2m} t^2$$

$$\overset{\downarrow}{vol} = area^2 \, \frac{\overset{\downarrow}{P^*} \overset{\downarrow}{t^2}}{2\underset{\uparrow}{m}}$$

As previously stated ↓ indicates known values so the area can be solved for:

$$(6) \qquad area = \sqrt{\frac{\overset{\downarrow}{vol} \times 2\overset{\downarrow}{m}}{\underset{\uparrow}{P^*}\underset{\uparrow}{t^2}}}$$

<u>Terminal Velocity</u>

When the P^* for equation (6) is set and the area of open venting required is calculated, no account of the resistance of friction was taken. The next step is therefore to include this to give a more accurate equation.

The friction force will oppose the drive of the P^* force, meaning that a given P^* will result in a smaller acceleration and therefore velocity than projected, with a consequent decrease in interior pressure change/time.

The friction (f) offered by a given area of venting is related to the vent design, and the velocity of airflow.

$f = kv$ for low wind speeds
$f = kv^2$ for higher wind speeds

In order to quantify the friction, tests must be run on the vent type chosen

(1) Maintain a known constant pressure difference.

(2) Measure the terminal wind speed through the vent, i.e., the maximum wind speed which results from that set pressure difference.

At terminal velocity (v_t)

for low speed wind $$P^* - kv_t = 0 \rightarrow v_t = \frac{P^*}{k}$$

for high speed wind $$P^* - kv_t^2 = 0 \rightarrow v_t = \sqrt{\frac{P^*}{k}}$$

Note that P^* represents a $\frac{force\,(ma)}{area}$

The total force will therefore be $\frac{ma}{area} \times vent\ cross\ sectional\ area$

Thus with a known set P^* and a recorded terminal velocity it is possible to calculate a value for k for that specific vent type. This value corresponds to a certain area of vent (i.e., vent surface area dictates total force (ma) exerted since driving force P^* is $\frac{ma}{area}$)

The equation:

(A) $$\frac{m\left(\frac{dv}{dt}\right)}{area} = P^* - \frac{kv}{area}$$

can be written from Newton's second law (low speed)

$$v_t = \frac{P^*}{k} \qquad P^* = \frac{ma}{area}$$

Using an area corresponding to the cross-sectional area of one vent is convenient since that is what k and vt values are based on.

Now (A) can be written

$$\text{(A)} \qquad m\frac{dv}{dt} = ma - kv \qquad \text{and} \qquad v_t = \frac{ma}{k}$$

divide (A) by -k

$$\frac{-m}{k}\frac{dv}{dt} = \frac{-ma}{k} + v$$

substitute $-v_t$ for $\frac{-ma}{k}$

$$\frac{-m}{k}\frac{dv}{dt} = -v_t + v$$

$$\int_0^t \frac{-k}{m}dt = \int_0^v \frac{1}{v - v_t}dv$$

$$\frac{-k}{m}t = \ell n\frac{v_t - v}{v_t}$$

$$e^{\left(\frac{-k}{m}\right)t} = 1 - \frac{v}{v_t}$$

$$\text{(B)} \qquad v = v^t\left(1 - e^{-\frac{k}{m}t}\right)$$

Equation (B) can be substituted into equation (1). The definite integral of equation (B) between any two time limits will be a more accurate replacement for the v (average velocity) multiplied by t (time air is flowing) portion of equation (1).

$$volume = total\ vent\ area \times \int_0^t v_t\left(1 - e^{-\frac{k}{m}t}\right)$$

$$\int_0^t v_t - v_t e^{-\frac{k}{m}t} = \left[v_t t + v_t \frac{m}{k} e^{-\frac{k}{m}t}\right]_0^t$$

(D) $$\text{Total Vent Area} = \frac{vol}{\left[v v_t + v_t \frac{m}{k} e^{-\frac{k}{m}t}\right]_0^t}$$

Equation (D) would be correct for low velocities of air flow where $f = kv$.
For high velocity where $f = kv^2$

$$P^* - kv^2 = 0 \ \ at \ \ v_t$$

$$v_t = \sqrt{\frac{P^*}{k}} = \sqrt{\frac{ma}{k(area)}}$$

Again, make the area the area of the roof vent since k & vt are calculated from that.

$$m\frac{dv}{dt} = ma - kv^2$$ divide both sides by k

$$\frac{m}{k}\frac{dv}{dt} = \frac{ma}{k} - v^2$$ substitute $v_t^2 = \frac{ma}{k}$

$$\frac{m}{k}\frac{dv}{dt} = v_t^2 - v^2$$

$$\frac{m}{k}\left(\frac{1}{dt}\right) = \frac{v_t^2 - v^2}{dv}$$

$$\frac{k}{m}dt = \frac{1}{v_t^2 - v^2}dv$$

$$\int_0^t \frac{k}{m}dt = \int_0^v \frac{1}{v_t^2 - v^2}dv$$

$$\frac{k}{m}t = \frac{1}{2v_t}\ell n\left|\frac{v_t + v}{v_t - v}\right|$$

$$2v_t\frac{k}{m}t = \ell n\left|\frac{v_t + v}{v_t - v}\right|$$

$$e^{\left(\frac{2v_t k}{m}\right)t} = \frac{v_t + v}{v_t - v}$$

(E) $$\left[v = \frac{v_t e^{\left(\frac{2v_t k}{m}\right)t} - v_t}{1 + e^{\left(\frac{2v_t k}{m}\right)t}} \right]$$

As before the definite integral of equation (E) will be a more accurate replacement for the v (average velocity) x t (time air is flowing) portion of equation (1).

$$(1) \qquad \text{vol} = \text{total vent area} \times \int_0^t \frac{v_t e^{\left(\frac{2v_t k}{m}\right)t} - v_t}{1 + e^{\left(\frac{2v_t k}{m}\right)t}}$$

let $c = \dfrac{2v_t k}{m}$ to make the notation easier

$$\int \frac{v_t e^{ct} - v_t}{1 + e^{ct}} dt = -v_t \int \frac{1 - e^{ct}}{1 + e^{ct}} dt = -v_t \int \left(1 - \frac{2e^{ct}}{1 + e^{ct}}\right) dt$$

$$= -v_t \int 1 dt + \frac{2v_t}{c} \int \frac{e^{ct} c}{1 + e^{ct}} dt$$

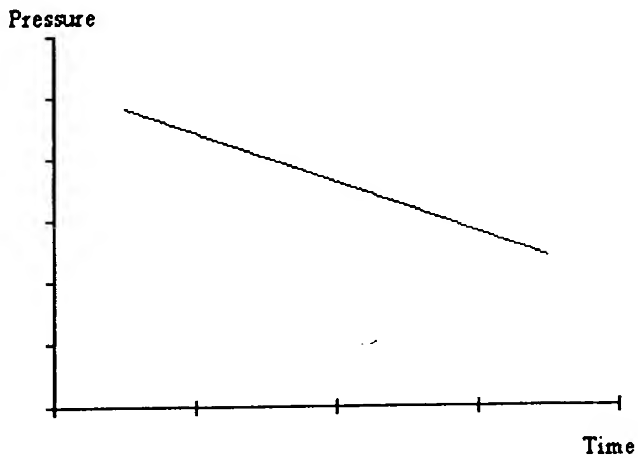
$$\left[\begin{array}{l} \textit{let } u = 1 + e^{ct} \\ \therefore \dfrac{du}{dt} = e^{ct} c \\ \Downarrow \textit{substituting } u \textit{ and } \dfrac{du}{dt} \\ \displaystyle\int \frac{\frac{du}{dt} dt}{u} \end{array}\right]$$

$$= \left[-v_t t + \frac{2v_t}{c} \ell n\left(1 + e^{ct}\right)\right]_0^t$$

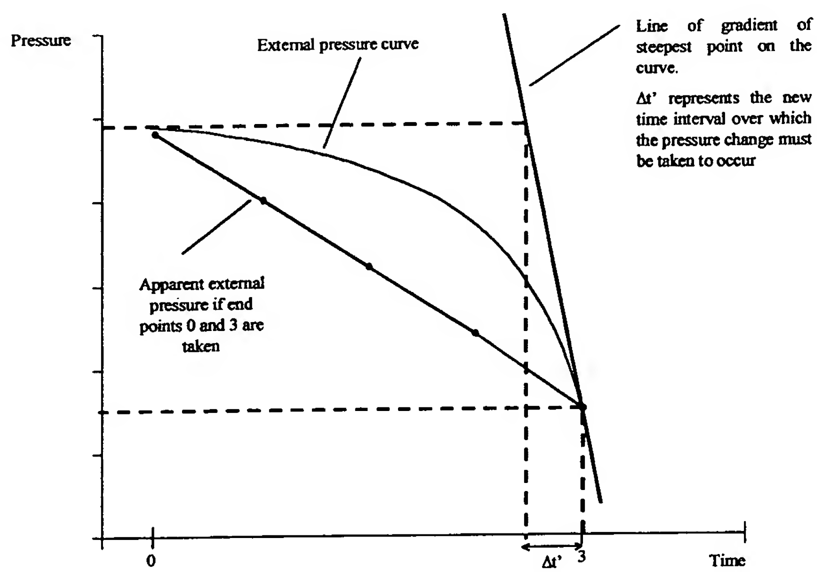
Equation F

$$\text{Total Vent Area} = \frac{Vol}{\left[-v_t t + \dfrac{m}{k} \ell n\left(1 + e^{\frac{2v_t k}{m} t}\right)\right]_0^t}$$

These equations are true for the straight-line scenario of external pressure change.



They hold true for any pressure drop, which is a straight-line graph between two time points. They are therefore also true for a curved graph pressure drop as long as the increment t taken is tended to 0 (i.e., very small so appears like a straight line).



Looking at the previous example graph, if equations (6), (D) or (F) are used with the end points $t = 0$, $t = 3$, the predicted vent surface area required will correspond to the straight-

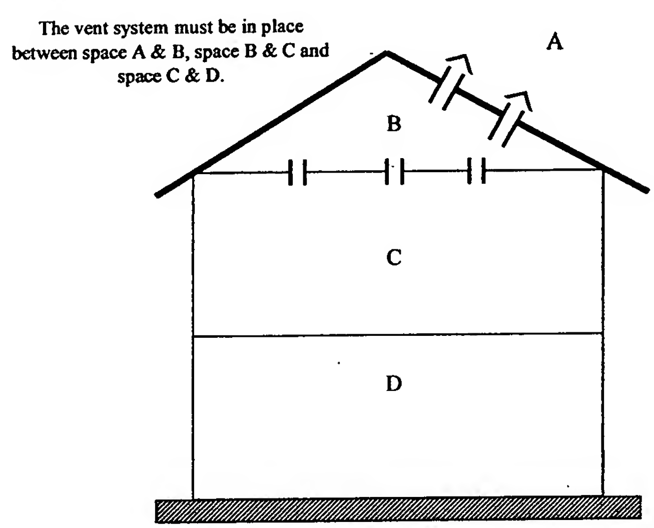
line pressure change. P^* will go above and below the preset constraint and so will not represent a maximum allowable P^*.

To get a solution for vent surface area that most accurately and completely constrains the maximum allowable P^*, the point at the steepest gradient of the curve must be taken. Using that gradient line, apply the equations (6), (D) or (F) (whichever is chosen as appropriate).

The vent area calculated from this will be the minimum required to absolutely ensure that the P^* designated represents a maximum allowable P^* (safety margins factored in).

SOME POINTS FOR OVERALL SYSTEM SETUP

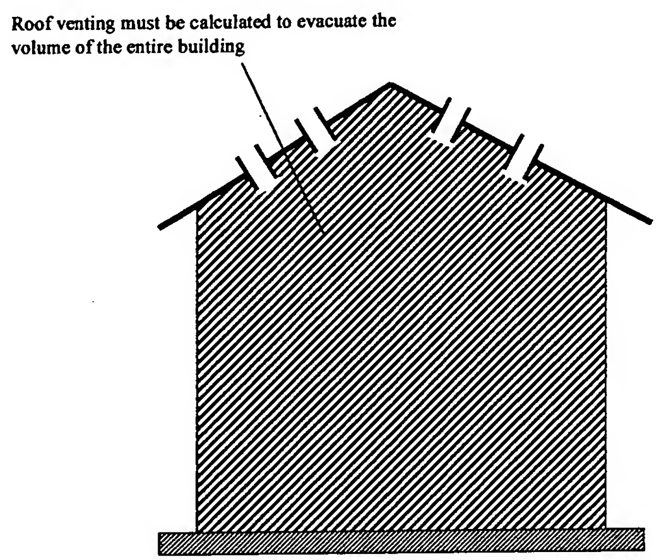
In many buildings/houses there may be a space below the roof.



The vent system must be in place between space A&B space B&C and space C&D.

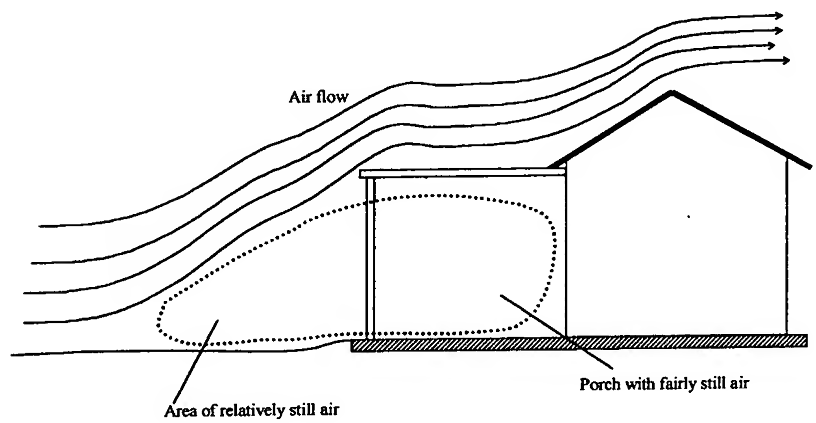
Between floors a stairway will probably be sufficient surface area (allow sufficient volume flow)

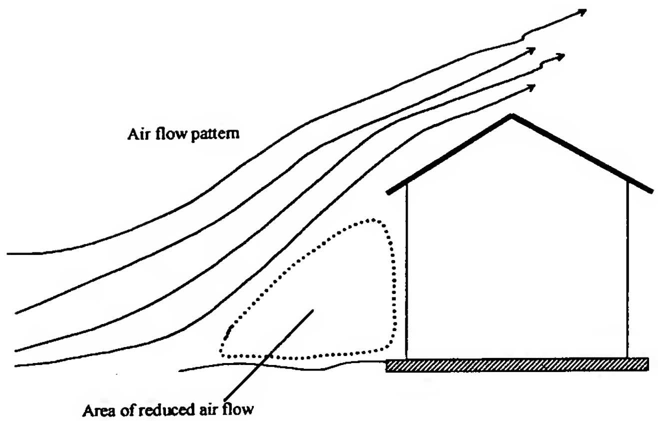
Rooms with doors that might potentially be closed must have vents. One would choose from equations (6), (D) or (F) to calculate the surface area of venting necessary to evacuate each room's volume.



EAVES AND PORCH/VERANDAHS

It will also be necessary to place vents in the eaves and any porches on a building.
What tends to happen in these regions is a build-up of pressure (still air) away from the building.

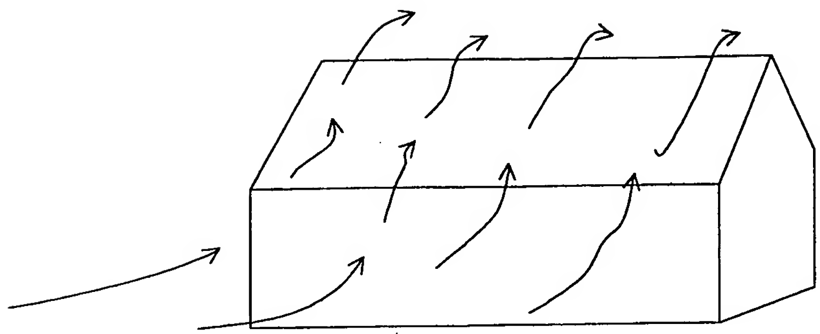




In order to quantify the vent area required place pressure sensors in the eaves and porch of a model structure. Then blow worst-case scenario test winds over the model and add vents until the acceptable $P*$ is achieved. A vent number/area is thus generated. Blow winds from all directions and use the maximum vent number/area value generated.

VENT PLACEMENT

The area calculated as being the minimum required to ensure that a roof does not blow off could be divided up into many vents, or it could be built as one giant vent. This system is designed to work when the whole roof (and thus the entire minimum required venting) is exposed to the high wind situation. The scenario depicted below shows a situation that requires a modification to the system's parameters. The pressure decrease due to high winds only occurs where there is high-speed airflow.



The design of the above building means that the minimum possible roof surface area exposed to high wind is ½ of the total roof surface area. The calculated minimum surface area of venting required, must therefore be present on both sides of the roof. (Pressure reduction due to drag/turbulence on the leeward half of the roof is ignored as a potential air evacuating force.)

It is apparent that the house profile must be studied, and the direction from which the wind blows over the least roof surface area ascertained. That roof surface area must have the calculated necessary area of venting to prevent roof loss. The same formula must be applied to every wind direction and related roof surface area exposed.